

## General Design Considerations

## Two options for the CDR:

-Ring-Ring collider

-Linac-Drift Tube Linac with Energy Recovery

## Interaction Region

## Planned timeline

## Next Steps and foreseen R&D activities

**On behalf of the LHeC Collaboration!**

# Design Considerations

LHC beams:  $E_p=7$  TeV; CM collision energy:  $E_{CM}^2 = 4 E_e^* E_{p,A} \rightarrow E_{\text{TeV}}$

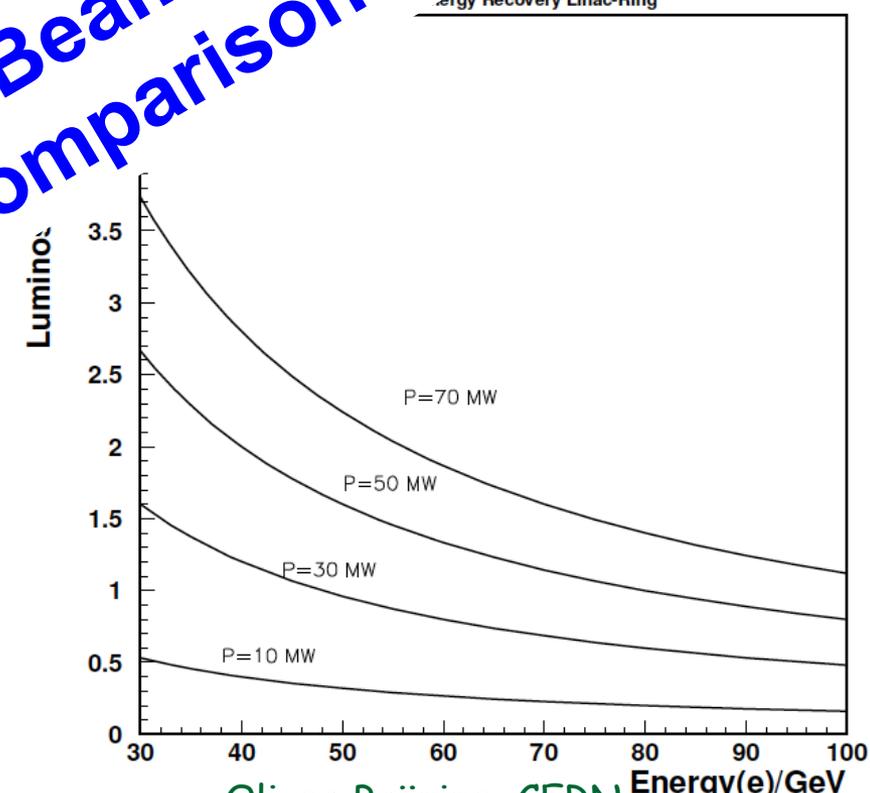
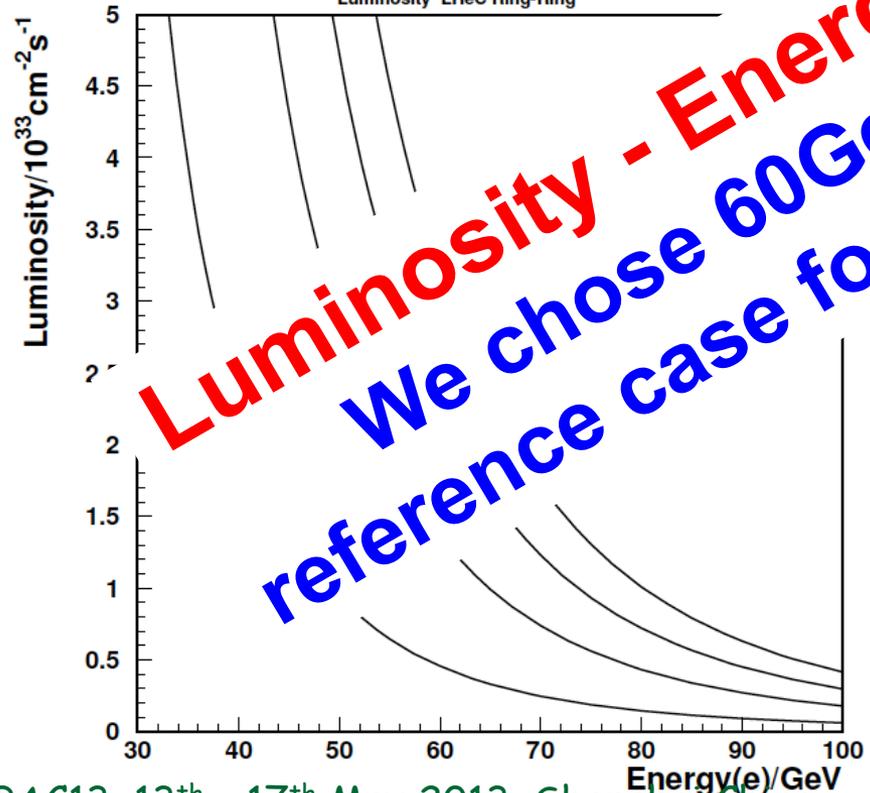
Luminosity  $> 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  with 100 MW power consumption  $\rightarrow$   $10^4 \text{ W}$

Integrated  $e^+p$  :  $O(100) \text{ fb}^{-1} \approx 100 * L(\text{HERA}) \rightarrow \text{synch}$

Start of LHeC operation together with HL-LHC (2022)

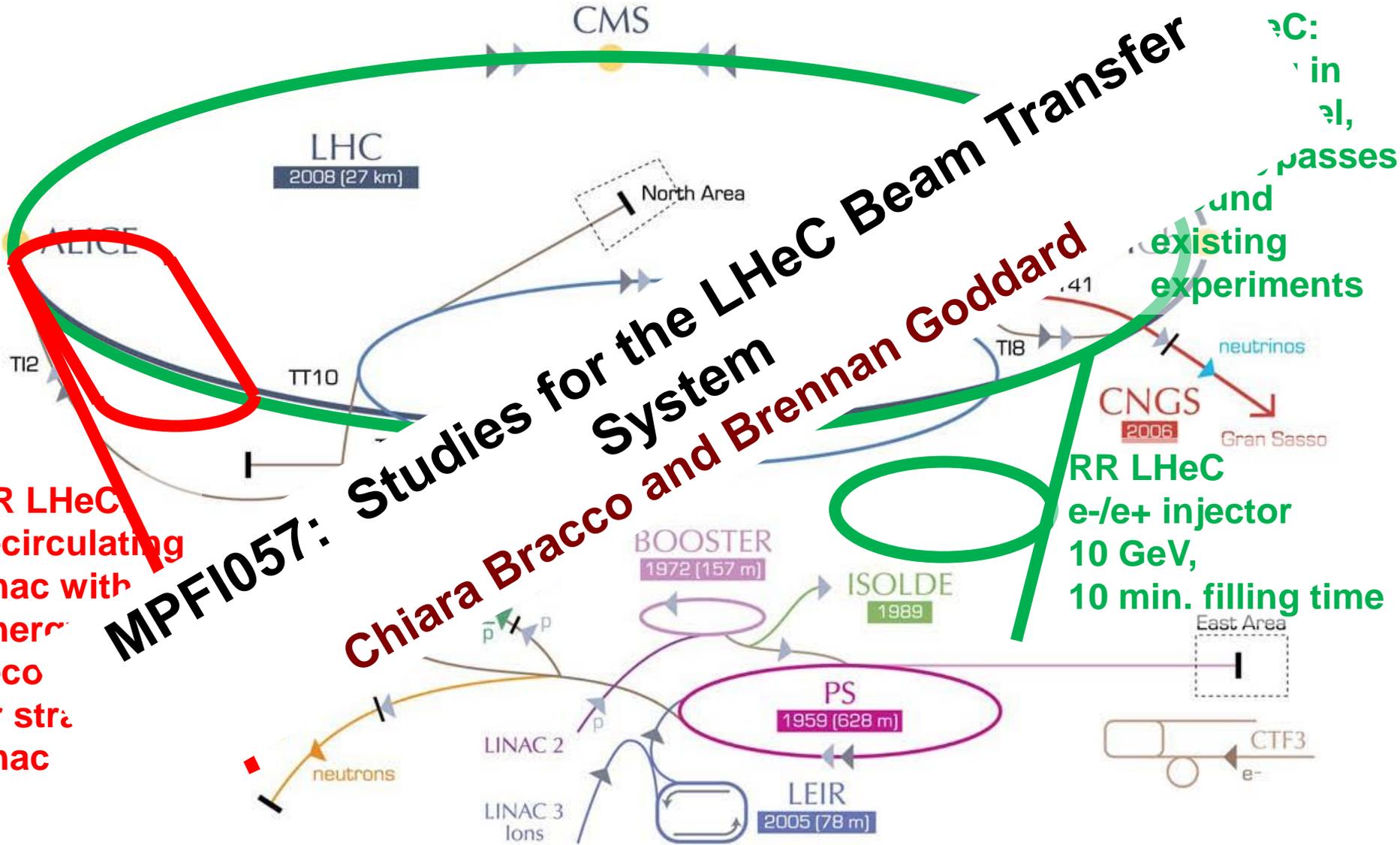
Ring in the LHC tunnel (Ring-Ring - RR)

Linac-Ring (Linac-Ring -LR)



**Luminosity - Energy & Power tradeoff**  
**We chose 60 GeV Beam Energy as reference case for comparison in the CDR**

# LHeC options: RR and LR



# LHeC CDR

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## Journal of Physics G Nuclear and Particle Physics

Volume 39 Number 7 July 2012 Article 075001

**A Large Hadron Electron Collider at CERN**  
Report on the Physics and Design Concepts for  
Machine and Detector  
*LHeC Study Group*



[iopscience.org/jphysg](http://iopscience.org/jphysg)

**IOP** Publishing

Journal of Physics G: Nuclear and Particle Physics

Vol. 39, No. 7, 075001

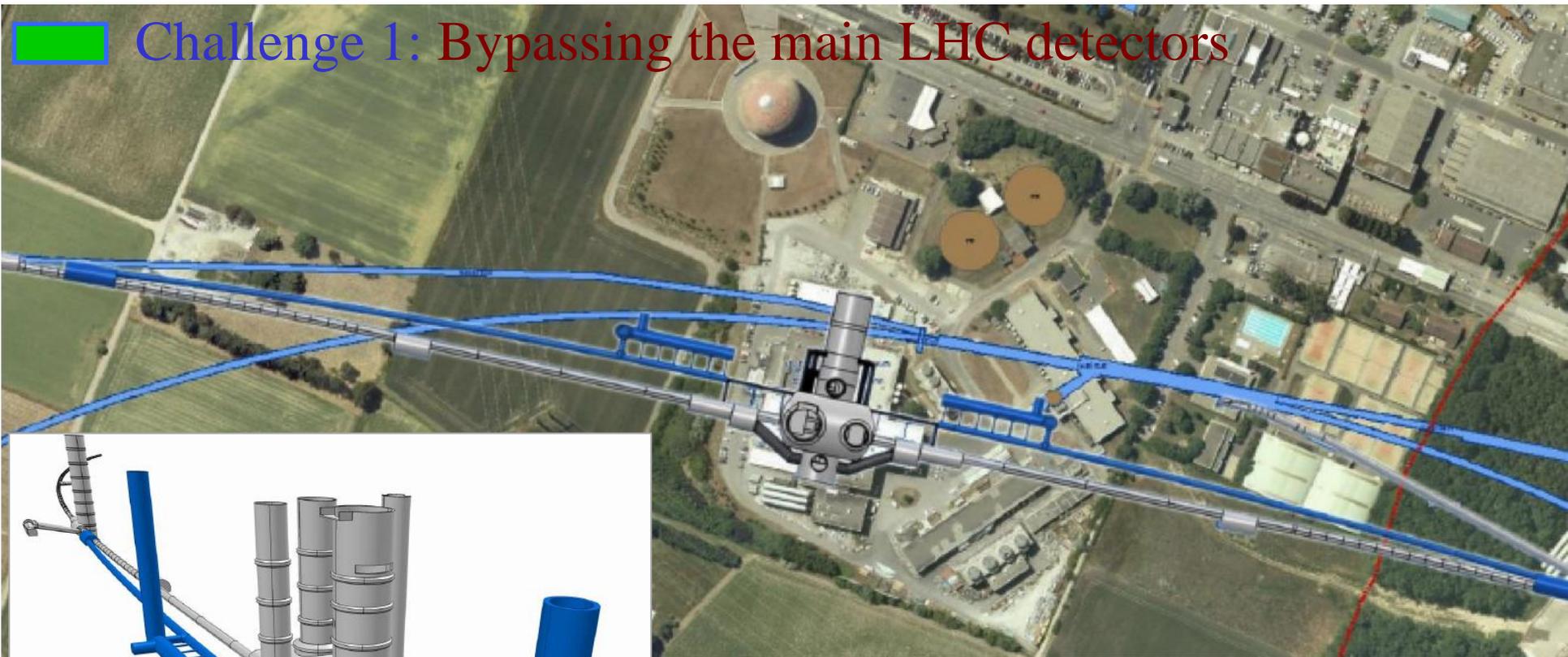
July 2012

1. Design for **synchronous ep and pp operation** (including eA) → after LS3 which is about 2025 – no firm schedule exists for HL-LHC, but it may operate until ~2035
2. LHeC is a new collider: the **cleanest microscope of the world**, a **complementary Higgs facility**, a unique QCD machine with a striking discovery potential, **with possible applications as  $\gamma\gamma \rightarrow H$**  or injector to TLEPP or others  
AND an exciting new accelerator project
3. **CERN Mandate to develop key technologies for the LHeC** for project decision after start of LHC Run II and in time for start parallel to HL LHC phase

# LHeC: Ring-Ring Option



Challenge 1: Bypassing the main LHC detectors



Without using the survey gallery the ATLAS bypass would need to be 100m away from the IP or on the inside of the tunnel!

For the CDR the bypass concepts were decided to be confined to ATLAS and CMS

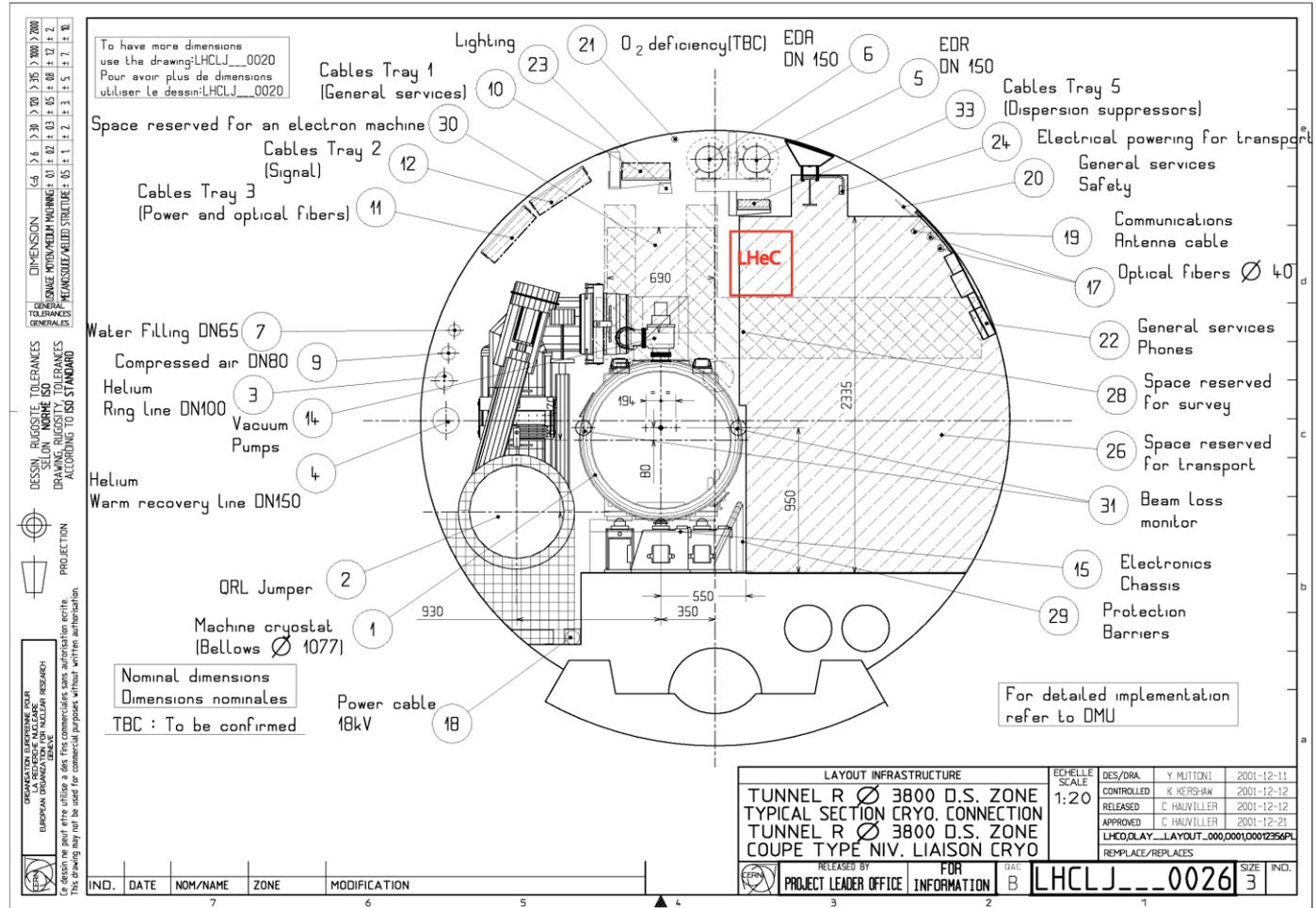
ca. 1.3 km long bypass

ca. 170m long dispersion free area for RF

# LHeC: Ring-Ring Option

## Challenge 2: Installation with LHC circumference:

requires:  
support  
structure  
with  
efficient  
montage  
and  
compact  
magnets



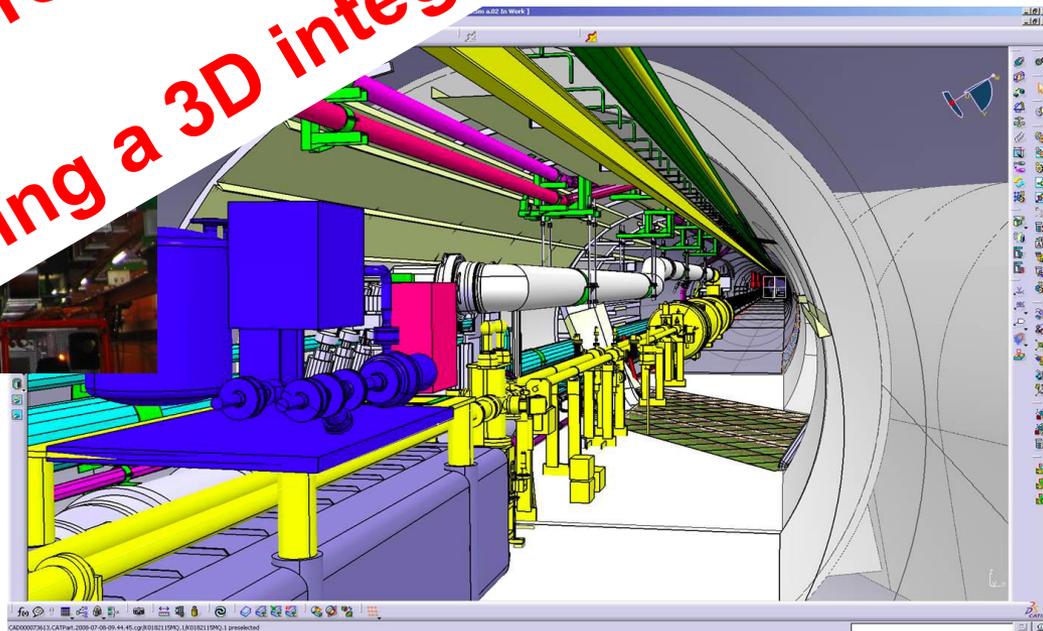
# LHeC: Ring-Ring Option



Challenge 3: Integration in the LHC tunnel

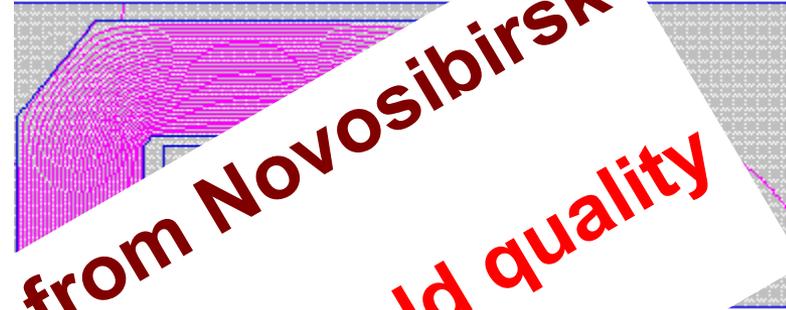
**No principal problem found yet!  
(But we are missing a 3D integration study)**

link in IR3



# LHeC Ring-Ring dipole 400 mm long CERN model

- interleaved ferromagnetic laminations
- air cooled
- two turns only, bolted bars
- 0.4 m models with different types of iron



**Similar prototype development from Novosibirsk**

**➔ Prototypes show that the required field quality and reproducibility is feasible!**

	$4 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
Average	$4 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
	$3 \cdot 10^{-5}$	$3 \cdot 10^{-5}$
	$4 \cdot 10^{-5}$	$5 \cdot 10^{-5}$
(0.5% Si steel)	$2 \cdot 10^{-5}$	$4 \cdot 10^{-5}$

[Tommasini]

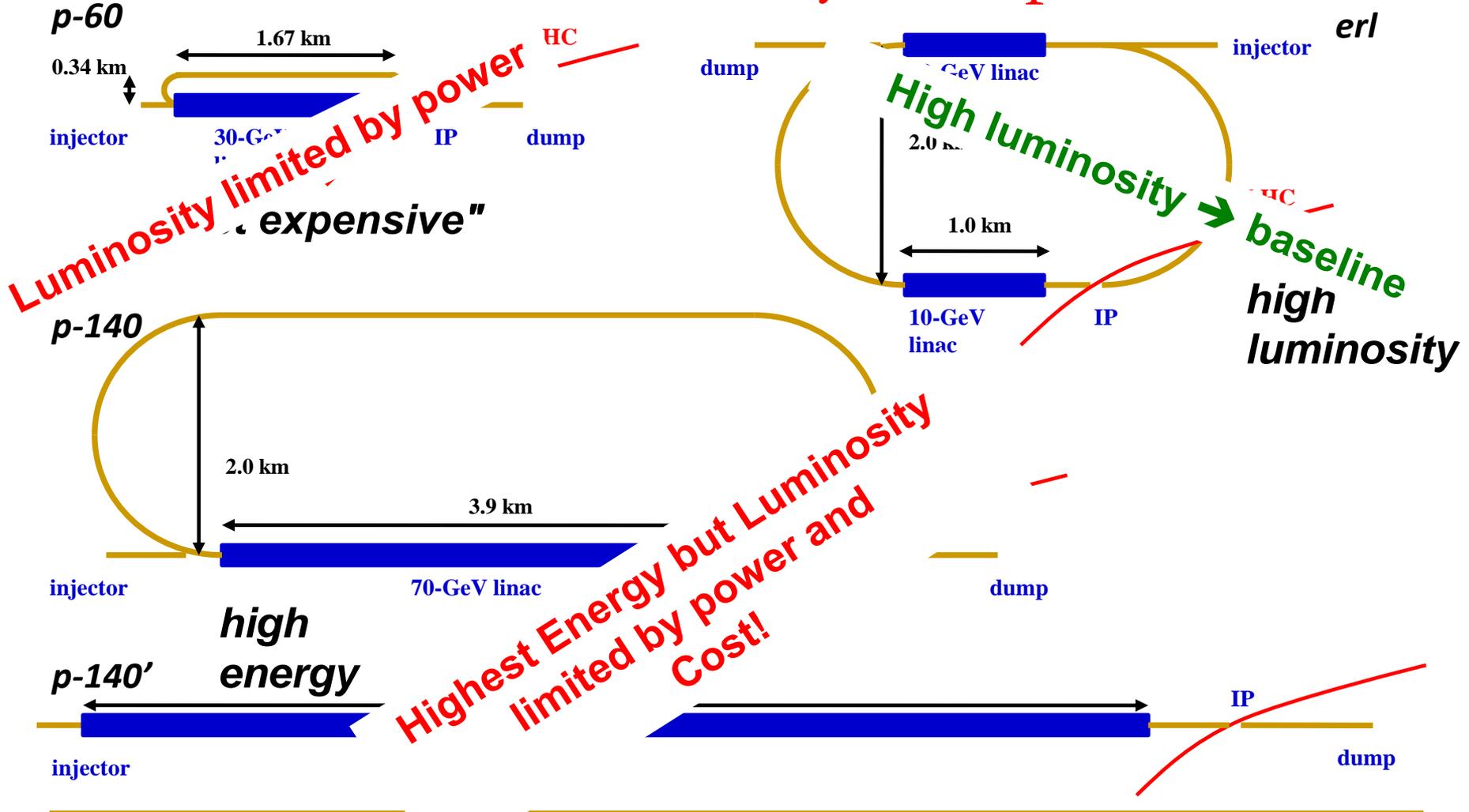
Full length magnet	
	60 (70)
	5.45
	127-763
Number of magnets	3080
Vertical aperture [mm]	40
Pole width [mm]	150
Number of coils	2
Number of turns/coil	1
Current [A]	1500
Conductor section [mmxmm]	92x43
Conductor material	aluminum
Magnet Inductance [mH]	0.15
Magnet Resistance [mΩ]	0.2
Power per magnet [W]	450
Cooling	air
Weight [tons]	1.5

Manufacture & tests of 3 models

# LHeC: Linac-Ring Option



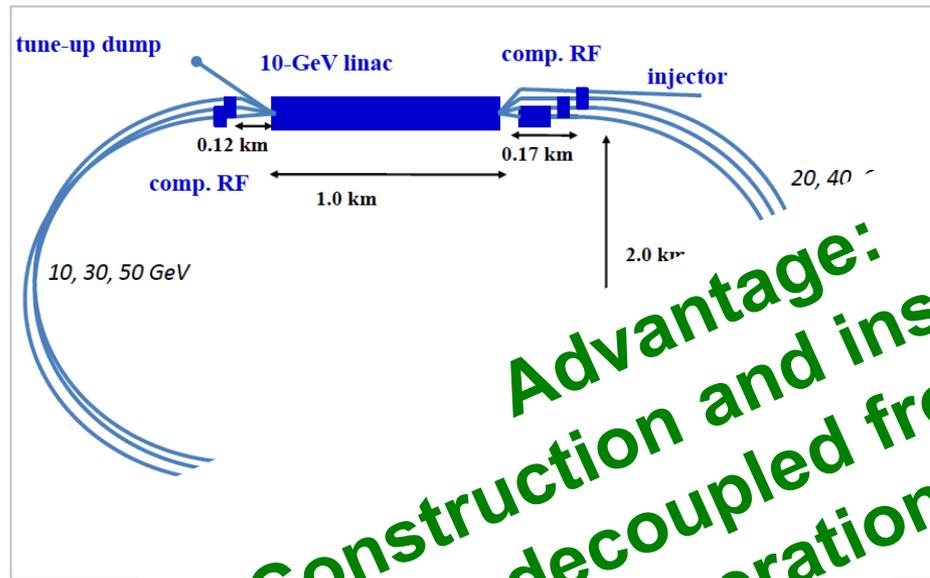
## Studied Various Layout Options



# LHeC: Baseline Linac-Ring Option



Challenge 1: Super Conducting Linac with Energy Recovery & high current ( $> 6\text{mA}$ )



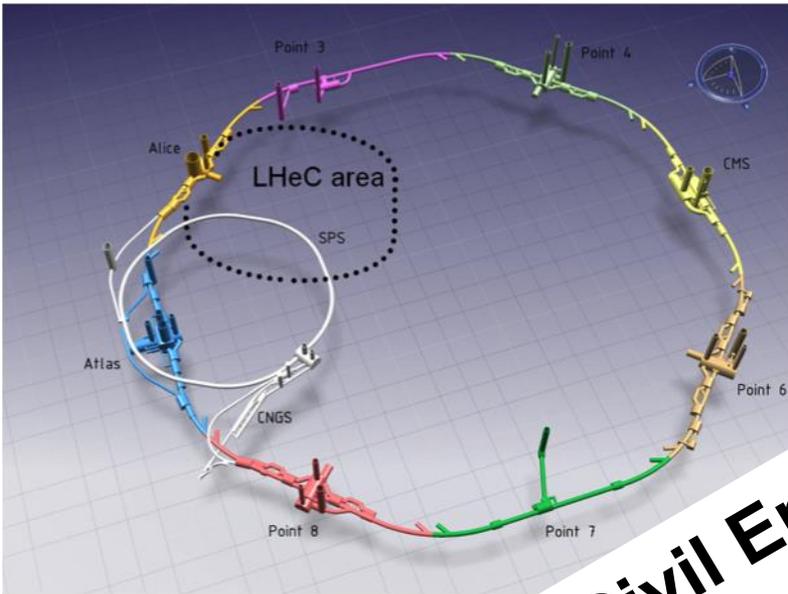
**Advantage:  
Construction and installation  
fully decoupled from LHC  
operation!**

100 m long SC  
CW operation

requires Cryogenic  
system comparable  
to LHC system!

- Challenge 2: large return arcs
- ca. 9 km ground tunnel installation (LHC / 3)
  - total of 1.5 km bending arcs
  - same magnet design as for RR option:  $> 4500$  magnets

# LINAC – Ring: Connection to the LHC



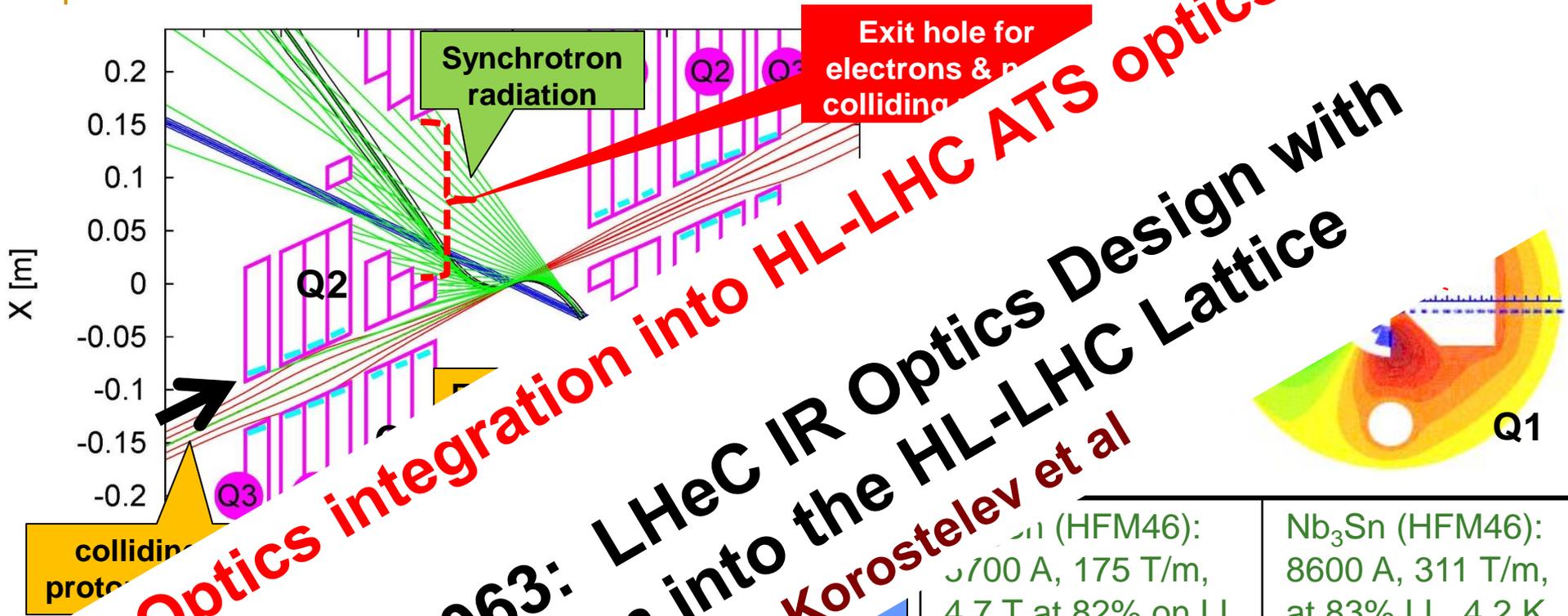
## MOPWO036: Civil Engineering Studies for Future Ring Colliders at CERN

John Osborne et al.

- ca. 1000 cavities
- 59 cryo modules per linac
- 721 MHz, 21 MV/m CW
- Similar to SPL, ESS, XFEL, ILC, eRHIC, Jlab
- 24 - 39 MW RF power
- 29 MW Cryo for 37W/m heat load
- 4500 Magnets in the 2 \* 3 arcs:
  - 600 - 4m long dipoles per arc
  - 240 - 1.2m long quadrupoles per arc

Linac (racetrack) inside the LHC for access at CERN Territory  
 $U=U(\text{LHC})/3=9\text{km}$

# LR LHeC IR layout & SC IR quadrupole



**Optics integration into HL-LHC ATS optics:**

**MOPWO063: LHeC IR Optics Design with Integration into the HL-LHC Lattice**

**Maxim Korostelev et al**

High-  
Nb<sub>3</sub>Sn  
low-field

poles based on  
on beam with common

<p>5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K</p>	<p>Nb<sub>3</sub>Sn (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K</p>
<p>46 mm (half) ap., 63 mm beam sep.</p>	<p>23 mm ap.. 87 mm beam sep.</p>
<p>0.5 T, 25 T/m</p>	<p>0.09 T, 9 T/m</p>

As shown by F. Zimmermann at Chamonix12

# Interaction Region Design



0.3

**Final parameter set will be developed as we gain experience with LHC operation (beam-beam, spacing etc.)**

**Performance reach of  $L > 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  seems to be well within reach of the LHeC!**

**MOPWO054: The LHeC as a Higgs Boson Factory**

**Frank Zimmermann et al**

20

10 12 14 16 18 20 22

# LHeC Planning and Timeline



We assume the LHC will reach the end of its lifetime with the end of the HL-LHC project:

-Goal of integrated luminosity of  $3000 \text{ fb}^{-1}$  with  $200\text{fb}^{-1}$  to  $300\text{fb}^{-1}$  production per year  $\rightarrow$  ca. 10 years of HL-LHC operation

-Current planning based on HL-LHC start in 2022

$\rightarrow$  end of LHC lifetime by 2032 to 2035

LHeC operation:

-Luminosity goal based on ca. 10 year exploitation time ( $\rightarrow 100\text{fb}^{-1}$ )

-LHeC operation beyond or after HL-LHC operation will imply significant cost overhead for LHC consolidation

## Ring-Ring option:

- We know we can do it: → LEP 1.5
- Challenge 1: integration in tunnel and co-existence with LHC HW
- Challenge 2: installation within LHC shutdown schedule

## Linac-Ring option:

- Installation decoupled from LHC operation and shutdown planning
- Infrastructure investment with potential exploitation beyond LHeC
- Challenge 1: technology → high current, high energy SC ERL
- Challenge 2: Positron source

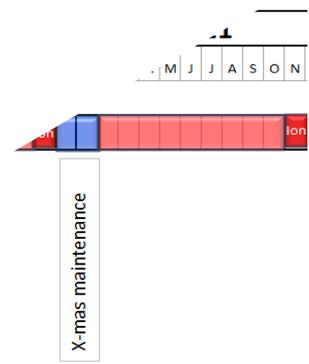
# Current 10 Year Plan for LHC Operation



**R-R Installation is very challenging within current schedule!**  
**LS1 and LS2 are too soon to be used for LHeC activities inside LHC tunnel!**



**→ Decision to adopt L-R Option as the LHeC baseline**



**2022**  
**LS3**  
 Installation of the HL-LHC hardware  
 Installation of LHeC  
 Preparation for HE-LHC

# CERN Mandate: 5 main points

The mandate for the technology development **includes studies and prototyping of the following key technical components:**

- **Superconducting RF** system for CW operation in an Energy Recovery Linac (high  $Q_0$  for efficient energy recovery)
- **Superconducting magnet development** of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models
- Studies related to the **experimental beam pipes** with large beam acceptance in a high synchrotron radiation environment
- **The design and specification of an ERL test facility** for the LHeC.
- **The finalization of the ERL design for the LHeC** including a finalization of the optics design, beam dynamics studies and identification of potential performance limitations

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators. Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies with existing CERN studies.**

S.Bertolucci at Chavannes workshop 6/12 based on

**CERN directorate's decision to include LHeC in the MTP**

# Post CDR Studies: ERL Beam Dynamics



Daniel Schulte @ LHeC Seminar 12. March 2013

## Beam-Beam effects:

$N=3 \cdot 10^9$

Beam-beam effect included  
as linear kick

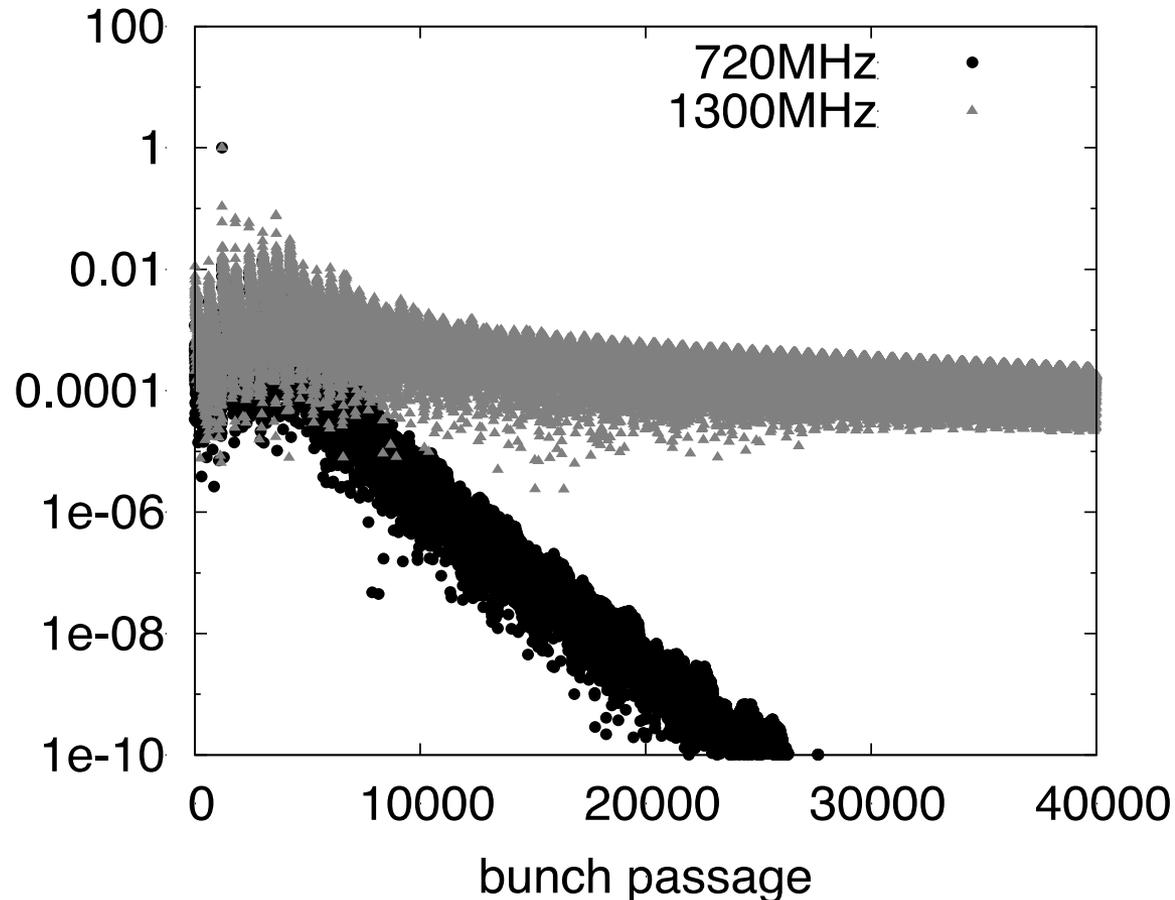
Result depends on seed for  
frequency spread  
“worst” of ten seed shown

$F_{\text{rms}}=1.135$  for ILC cavity

$F_{\text{rms}}=1.002$  for SPL cavity

Beam is stable but very  
small margin with 1.3GHz  
cavity

normalised offset



→ Optimum choice for LHeC RF frequency? → lower frequency

# Post CDR Studies: RF Frequency



Review of the SC RF frequency:

-HL-LHC bunch spacing requirements  
25ns (40.079 MHz)



**SPL and ILC frequencies are too far from LHeC requirements to be directly applicable**

**→ Decision to optimize frequency for CERN needs**

**→ 801 MHz with synergies for HL-LHC HH RF system and optimization for RF power**

323GHz  
XFEL: 1.3 GHz

Frequency (MHz) from existing technologies!  
But have to be a multiple of the ERL symmetry is  
not a standard asymmetric bunch patterns

Launch SC RF and ERL R&D and Establish collaborations:

-SC RF R&D has direct impact on cryo power consumption

-Synergy with HL-LHC and TLEP!

-ERL is a hot topic with many applications

-Synergy with national research plans: e.g. JLab, BNL eRHIC and MESA

Magnet R&D activities:

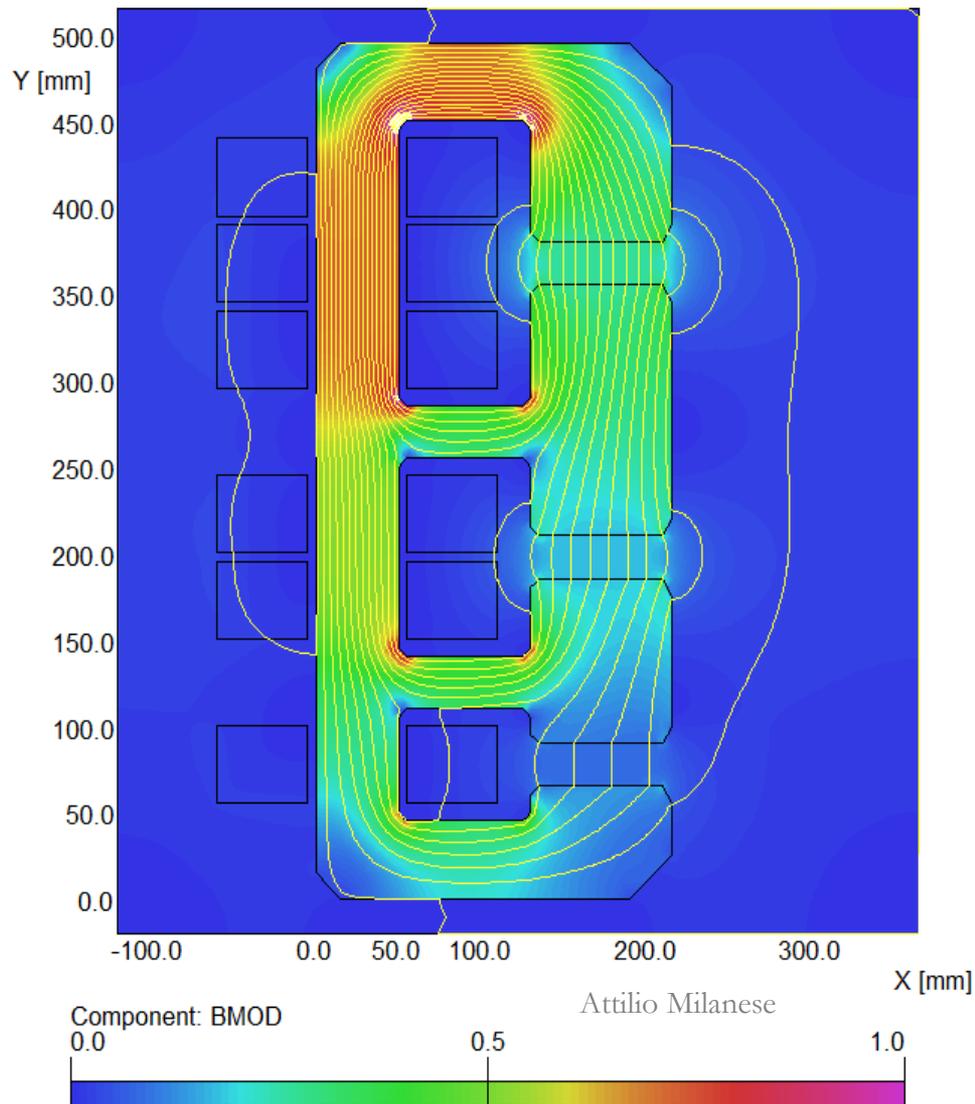
-Normal conducting compact magnet design ✓

-Superconducting IR magnet design

➔ Detailed magnet design depends on IR layout and optics

➔ Optics & IR magnet design influence experimental vacuum beam pipe

# Next Steps: Magnet Optimization



## First conceptual cross-section

flux density in the gaps	0.264 T 0.176 T 0.088 T
magnetic length	4.0 m
vertical aperture	25 mm
pole width	85 mm
number of magnets	584
current	1750 A
number of turns per aperture	1 / 2 / 3
current density	0.7 A/mm <sup>2</sup>
conductor material	copper
resistance	0.36 mΩ
power	1.1 kW
total power 20 / 40 / 60 GeV	642 kW
cooling	air

# LHeC: Post CDR Plan



Develop an ERL test facility @ CERN

-Beam Dynamics for ERL operation

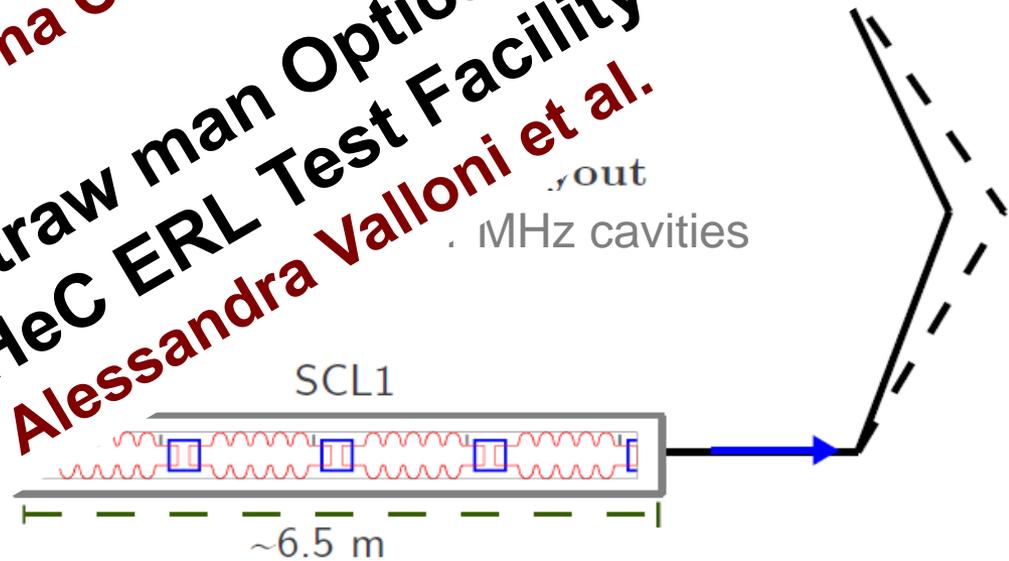
-Synergy with other research

ERN

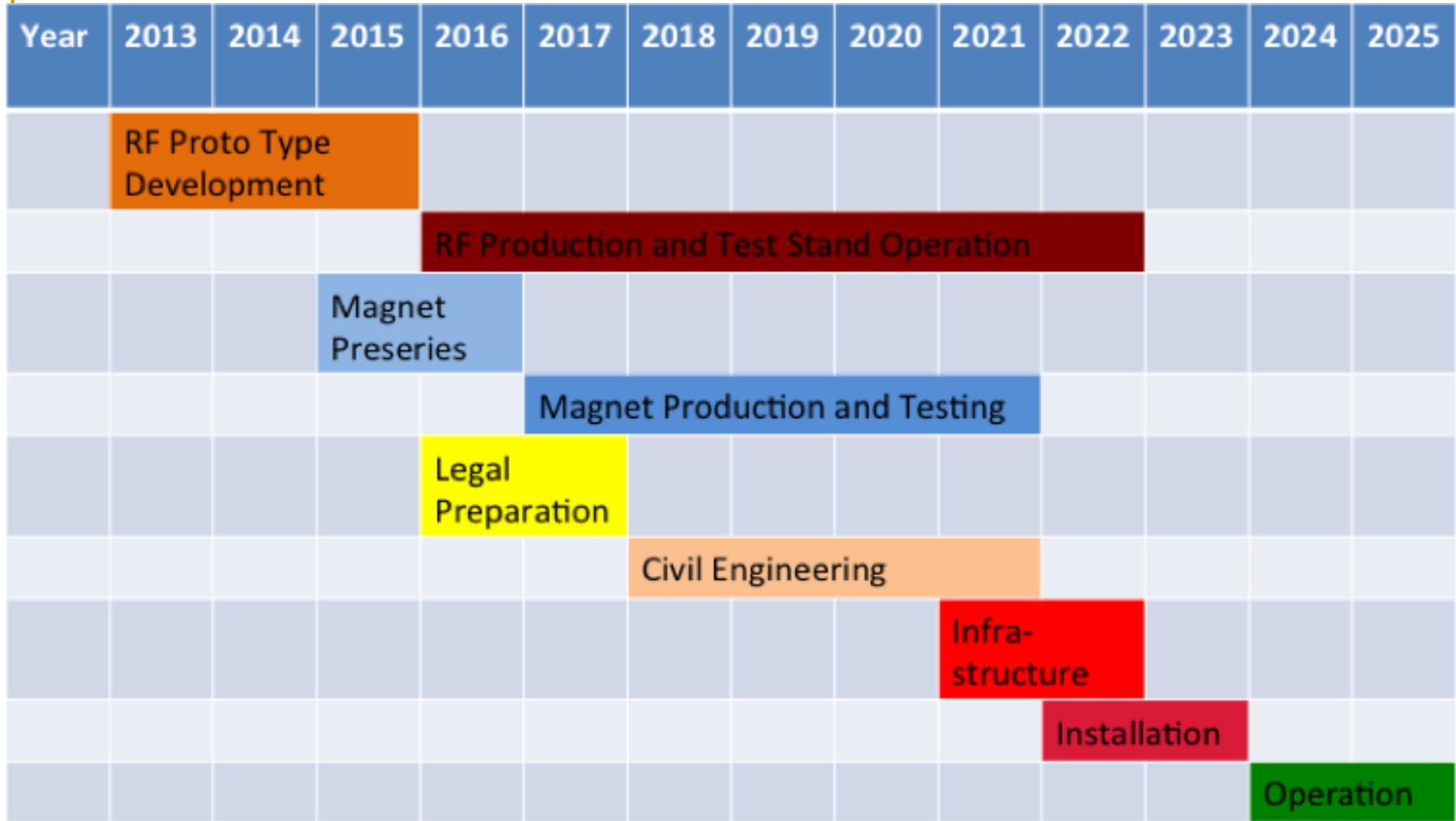
Dump

**WEPWO049: A PROPOSAL FOR AN ERL TEST FACILITY AT CERN**  
*Rama Calaga et al.*

**TUPME055: Straw man Optics design for the LHeC ERL Test Facility**  
*Alessandra Valloni et al.*



# LHeC Tentative Time Schedule



LS3 --- HL LHC

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL). In

# Summary



LHeC Project is on track for startup with HL-LHC:

-10 years for the LHeC from CDR to project start.

(Other smaller projects like ESS and PSI XFEL plan for 8 to 9 years [TDR to project start] and the EU XFEL plans for 5 years from construction to operation start)

HERA required ca.10 years from proposal to completion

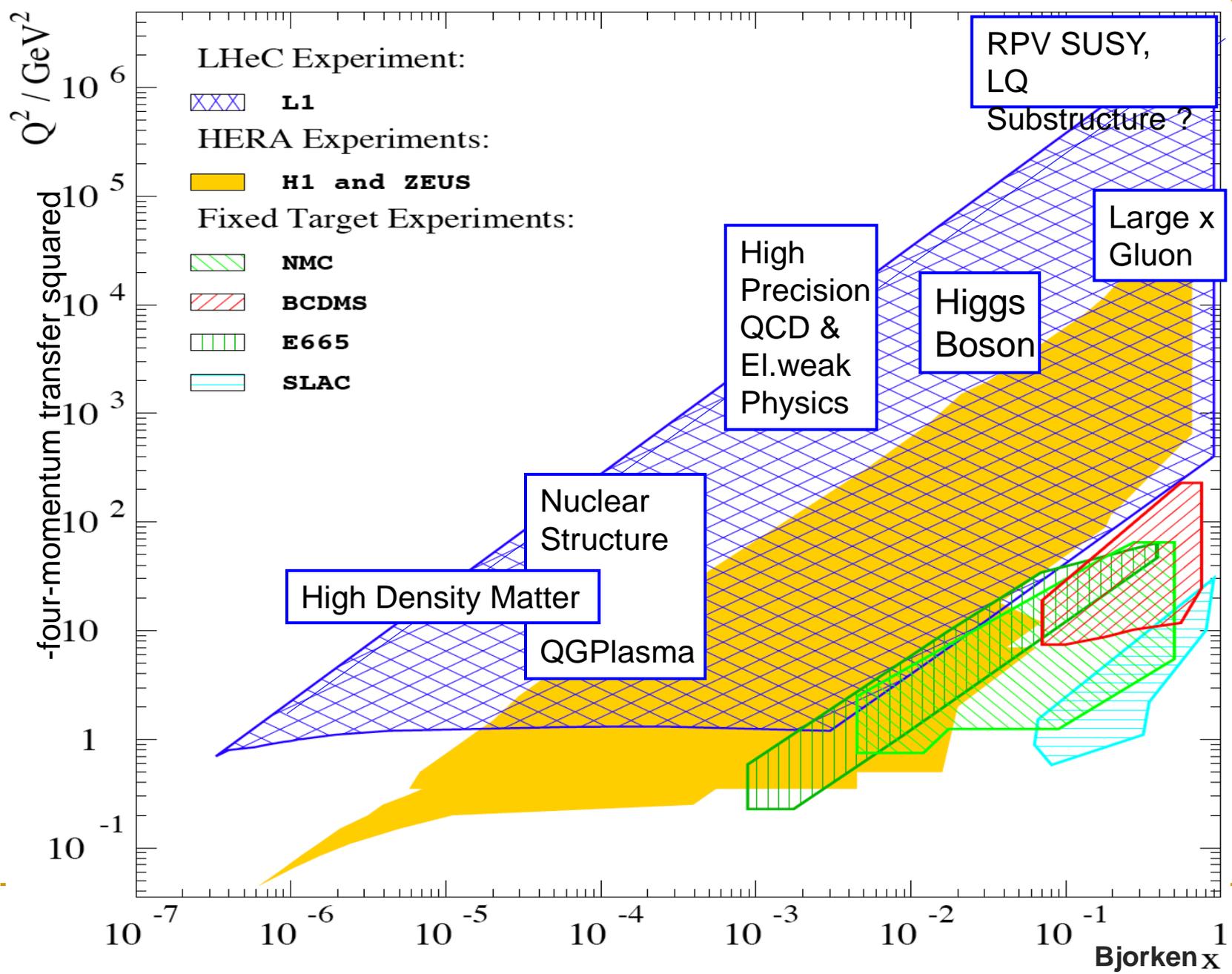
On schedule for launching SC RF development

LHeC ERL Test facility as a multi-purpose installation

RF studies and beam tests → Synergies with HL-LHC and TLEP

# Reserve Transparencies





# Design Parameters

electron beam	RR**	LR	LR*
e- energy at IP[GeV]	60	60	140
luminosity [ $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ ]	0.9	10	
polarization [%]	40	90	
bunch population [ $10^9$ ]	20		
e- bunch length [mm]			
bunch interval [ns]			
transv. emit. $\gamma\epsilon_{x,y}$ [m			
rms IP beam size			
e- IP betatron			
full			
gap			
rep.			
beam			5
ER effic.			N/A
average c		6.4	5.4
tot. wall pl	200	100	100

RR	LR
	1.7
	3.75
	7
	1.1

**Final parameter set to be developed as we gain experience with LHC operational (beam-beam, spacing etc)**

**The goal here is to demonstrate that realistic sets exist for both LHeC versions**

conservative  
also for deuterons  
(new) and lead (exists)

RR= Ring – Ring  
LR =Linac –Ring

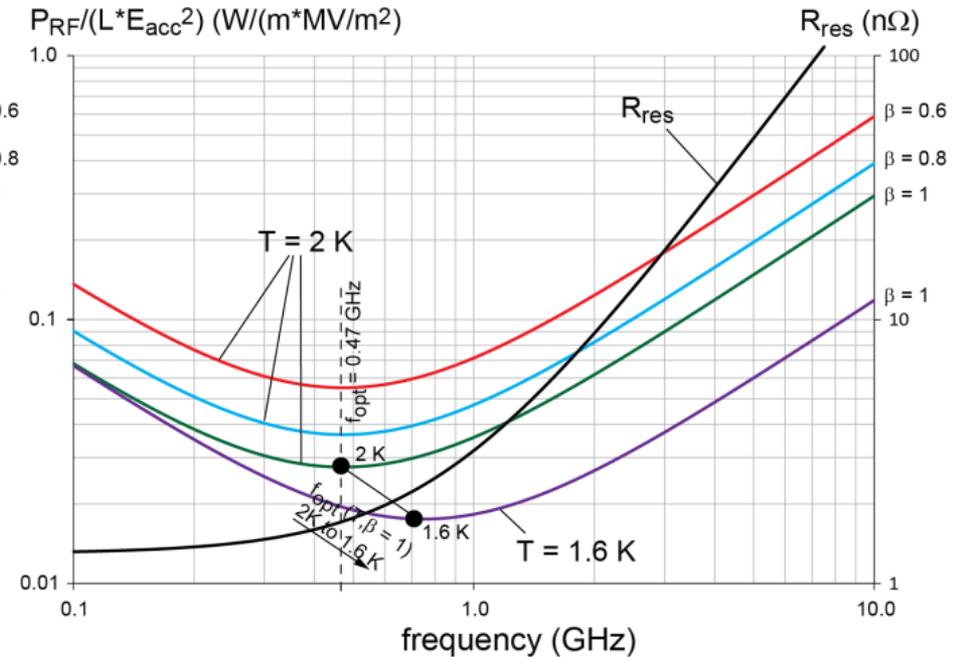
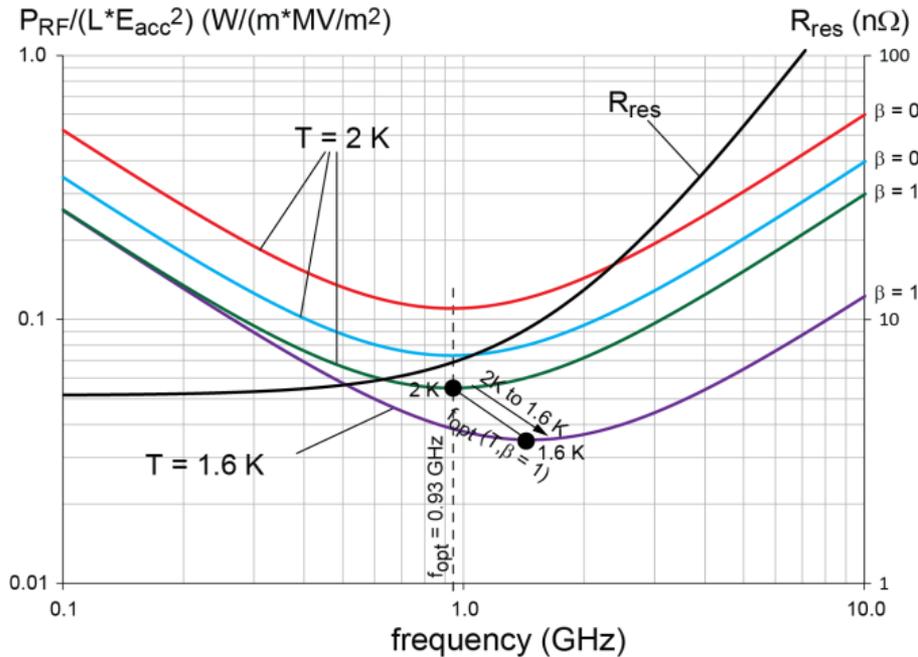
Ring uses 1° as baseline : L/2  
Linac: clearing gap: L\*2/3

\*) pulsed, but high; \*\*) impossible; \*\*) 1° acceptance optics

# Optimum RF Frequency: Power Considerations

Results from F. Marhauser

Erk Jensen at Daresbury meeting 12 March 2013

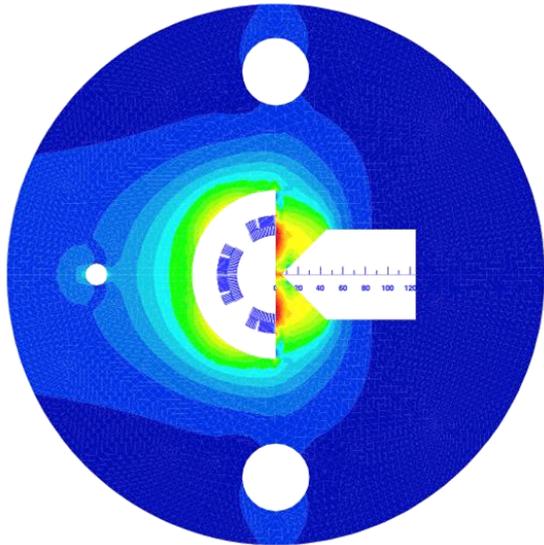


Small-grain (normal) Nb:  
Optimum frequency at 2K between  
700 MHz and 1050 MHz  
Lower T shift optimum f upwards

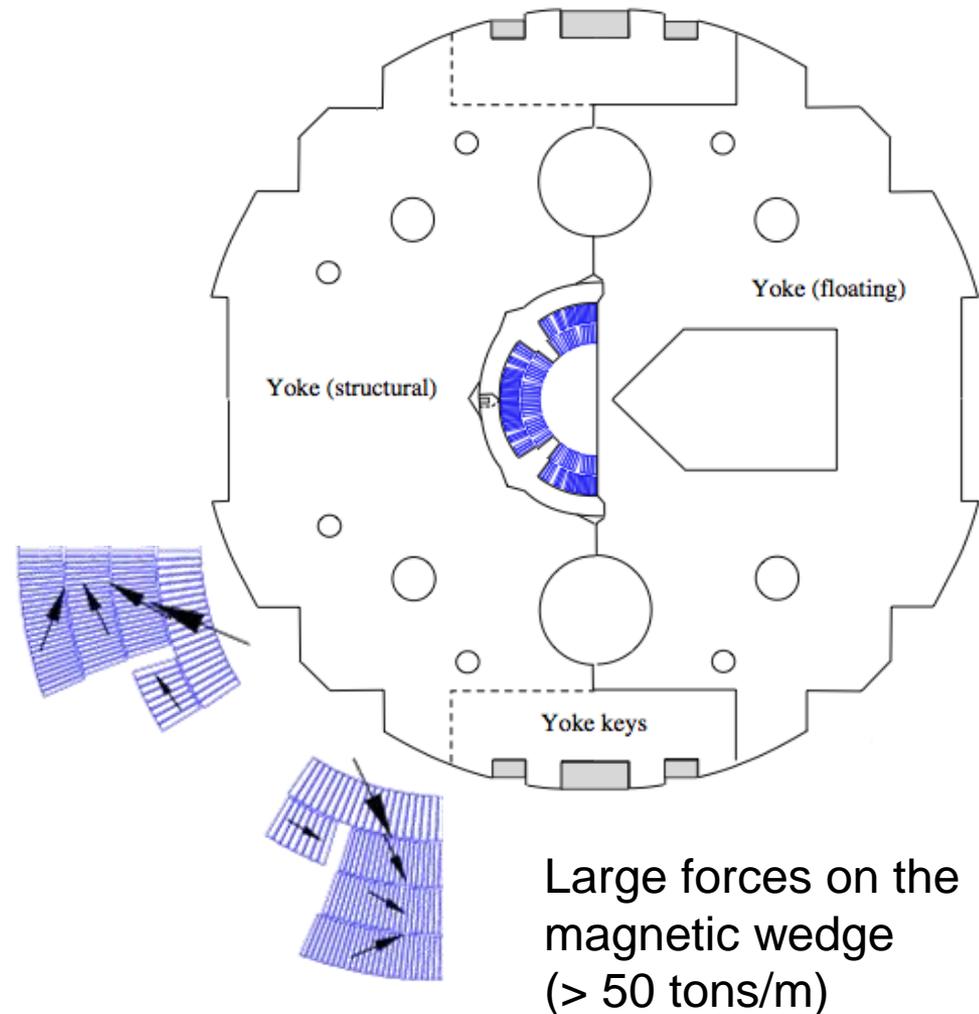
Large-grain Nb:  
Optimum frequency at 2K between  
300 MHz and 800 MHz  
Lower T shift optimum f upwards

# Next Steps: LHeC IR Quadrupole

Luca Bottura @  
Chamonix 2012

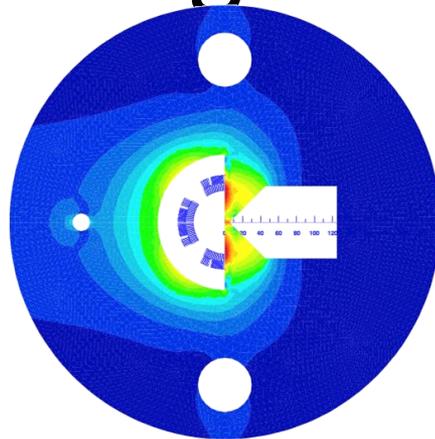


- Half-quad with field-free region, assembled using MQXC coils
  - 2.5 FTE
  - 500 kCHF
  - approx. 2 years till test



# IR magnets

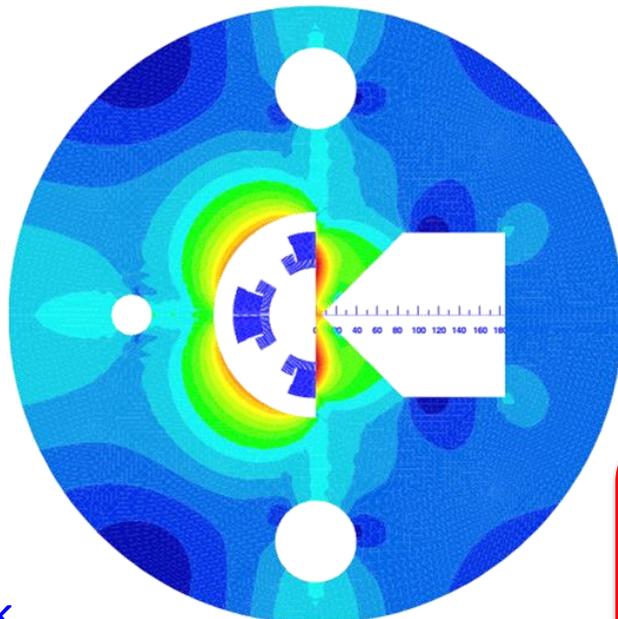
- Ring-ring
  - $G=140$  T/m
  - $A=70$  mm
  - $B_{\text{fringe}} = 30$  mT
  - **O(15) kW SR power in the proton aperture**



NbTi suitable for this *medium gradient* option

Mechanics ?  
Heat removal ?

- Linac-Ring
  - $G=250-300$  T/m
  - $A=90$  mm
  - $B_{\text{fringe}} = 500$  mT
  - **O(2) kW SR power in the proton aperture**



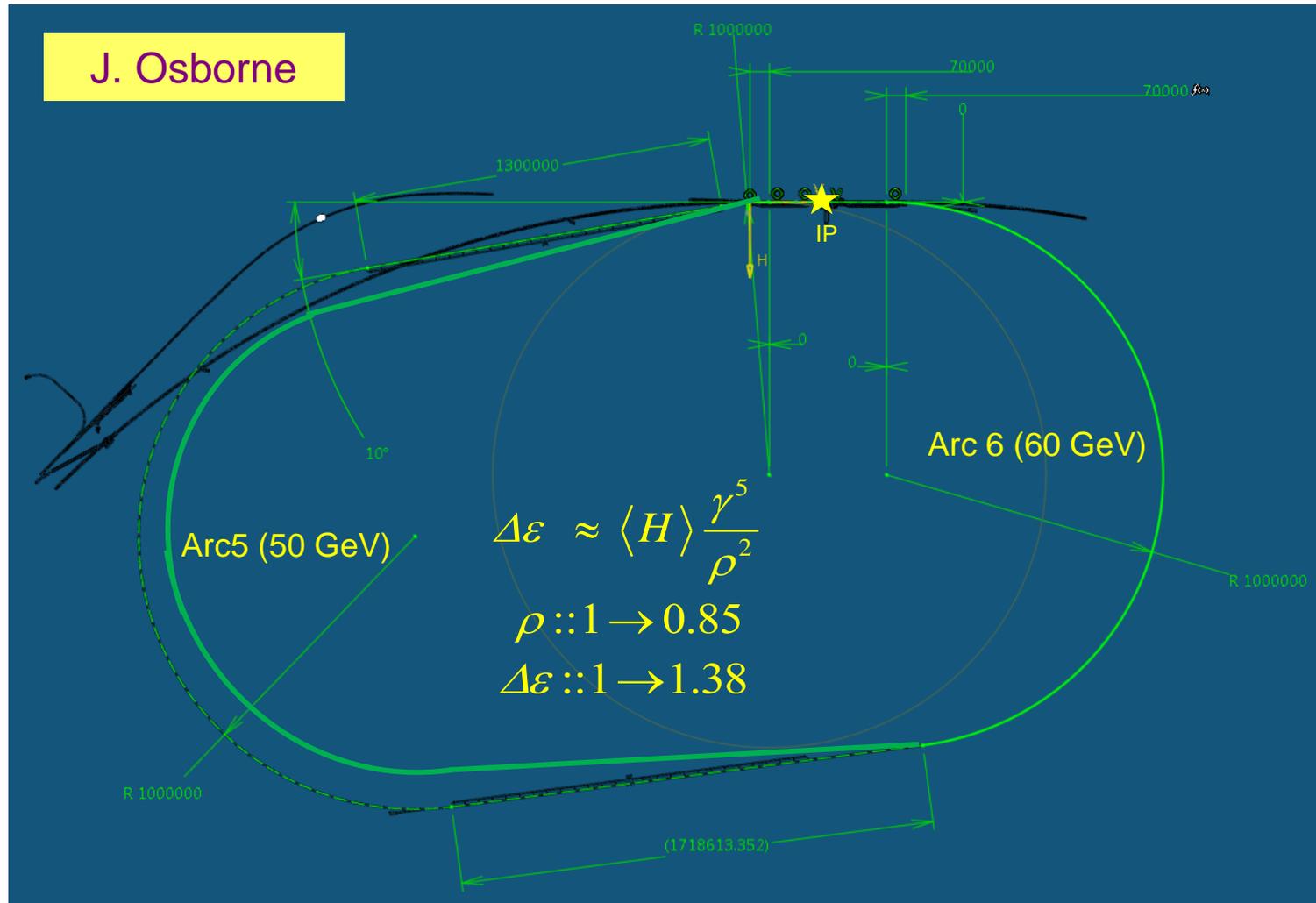
100 tons/m



NbTi or Nb3Sn ?  
Large aperture ?  
Mechanics ?  
Heat removal ?

By courtesy of S. Russenschuck

# Next Steps: ERL Layout Finalization



John Osborne

# LHeC - Participating Institutes: A very rich collaboration



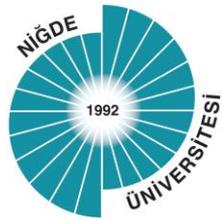
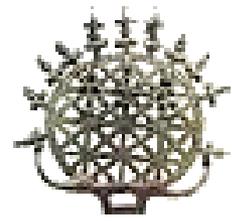
Norwegian University of Science and Technology



The Cockcroft Institute of Accelerator Science and Technology



Thomas Jefferson National Accelerator Facility



TOBB ETU



Physique des accélérateurs



Laboratori Nazionali di Legnaro



UNIVERSITY OF LIVERPOOL

**BROOKHAVEN**  
NATIONAL LABORATORY

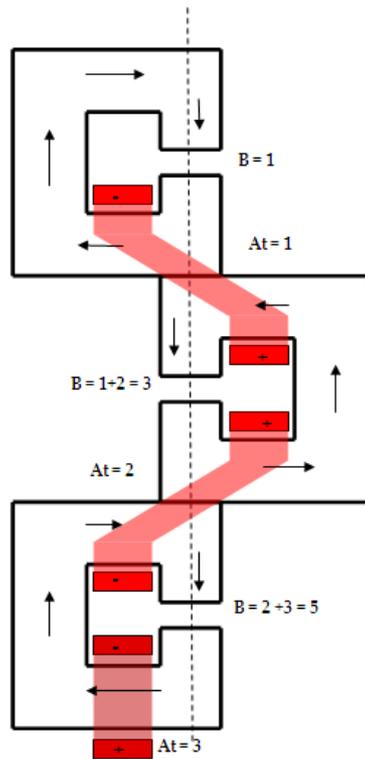


СИБИРСКОЕ ОТДЕЛЕНИЕ РАН  
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ  
им. Г.И.Будкера



KEK

# Next Steps: Test Facility and Magnets

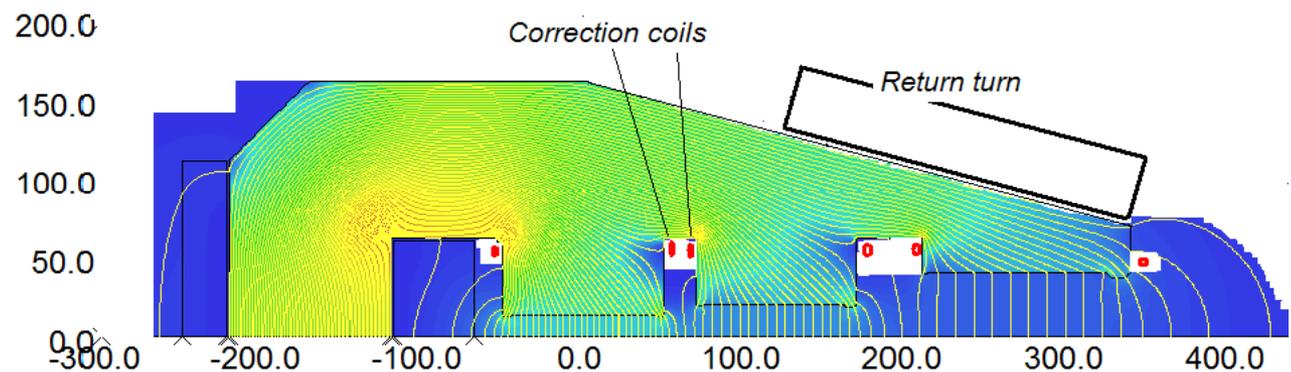


Neil Marks 7/12

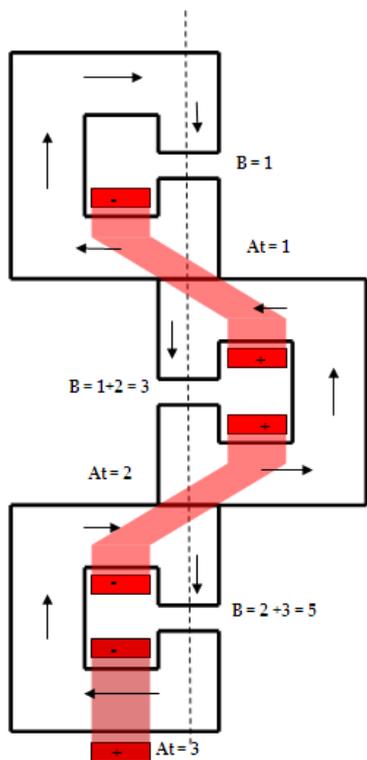
Intend to build Collaboration of CERN Magnet Group for the dipole and possibly further arc magnets for the Test Facility (two turns) and the LHeC.

Initial designs for Linac magnets in CDR and further discussions/thoughts from Daresbury, CERN and BINP colleagues.

Attilio Milanese and Yuri Pupkov 11/12



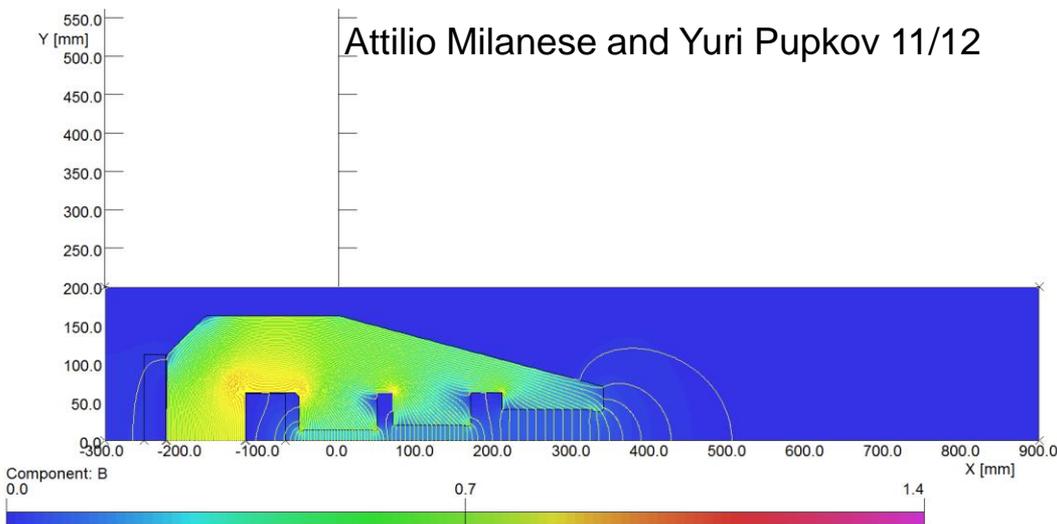
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Neil Marks 7/12

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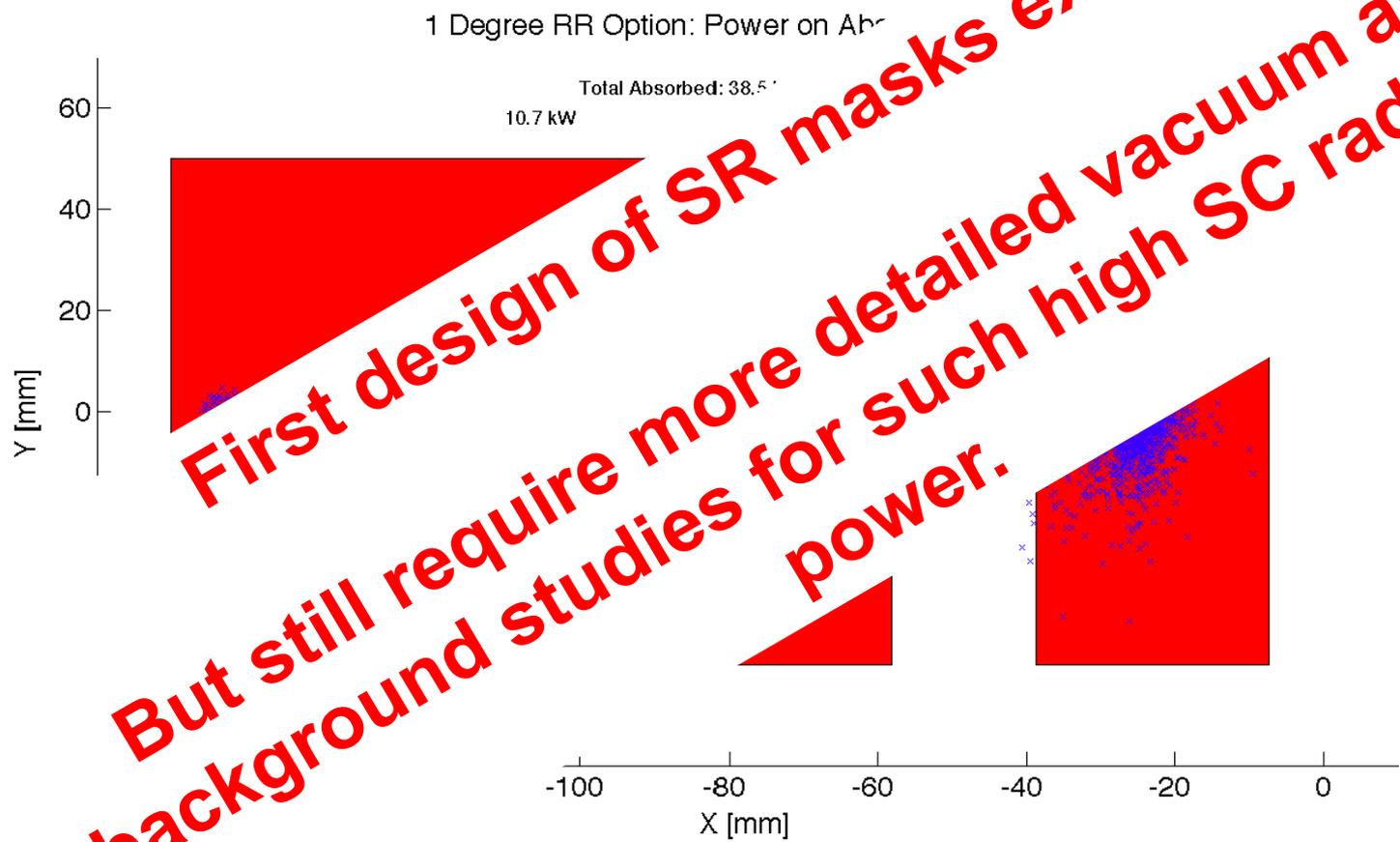
Initial designs for Linac magnets in CDR and further discussions/thoughts from Daresbury, CERN and BINP colleagues.



# Interaction Region: Synchrotron

tion

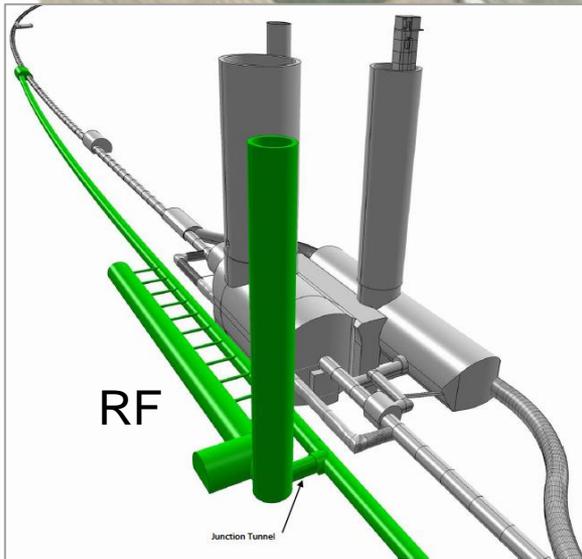
Significant power: > 20 kW. Example Ring-Ring



**First design of SR masks exists.**

**But still require more detailed vacuum and background studies for such high SC radiation power.**

# Bypassing CMS: 20m distance to Cavern



ca. 1.3 km long bypass  
ca. 300m long dispersion free area for RF installation

## Scientific Advisory Committee

Guido Altarelli (Rome)  
Sergio Bertolucci (CERN)  
Stan Brodsky (SLAC)  
Allen Caldwell -chair (MPI Munich)  
Swapan Chattopadhyay (Cockcroft)  
John Dainton (Liverpool)  
John Ellis (CERN)  
Jos Engelen (CERN)  
Joel Feltesse (Saclay)  
Lev Lipatov (St.Petersburg)  
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Richard Milner (Bates)  
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Guenther Rosner (Glasgow, NuPECC)  
Alexander Skrinsky (Novosibirsk)  
Anthony Thomas (Jlab)  
Steven Vigdor (BNL)  
Frank Wilczek (MIT)  
Ferdinand Willeke (BNL)

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Paul Newman (Birmingham)  
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Wesley Smith (Wisconsin)  
Bernd Surrow (MIT)  
Katsuo Tokushuku (KEK)  
Urs Wiedemann (CERN)  
Frank Zimmermann (CERN)

## Working Group Conveners

### Accelerator Design [RR and LR]

Oliver Bruening (CERN),  
Max Klein (Liverpool)

### Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),  
Uwe Schneekloth (DESY),  
Pierre van Mechelen (Antwerpen)

### Detector Design

Peter Kostka (DESY),  
Rainer Wallny (U Zurich),  
Alessandro Polini (Bologna)

### New Physics at Large Scales

George Azuelos (Montreal)  
Emmanuelle Perez (CERN),  
Georg Weiglein (Durham)

### Precision QCD and Electroweak

Olaf Behnke (DESY),  
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Claire Gwenlan (Oxford)

### Physics at High Parton Densities

Nestor Armesto (Santiago),  
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## Review Panel with experts on physics, detector, accelerator, specific systems

### QCD/electroweak:

Guido Altarelli, Alan Martin, Vladimir Chekelyan

### BSM:

Michelangelo Mangano, Gian Giudice, Cristinel Diaconu

### eA/low x

Al Mueller, Raju Venugopalan, Michele Arneodo

### Detector

Philipp Bloch, Roland Horisberger

### Interaction Region Design

Daniel Pitzl, Mike Sullivan

### Ring-Ring Design

Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

### Linac-Ring Design

Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

### Energy Recovery

Georg Hoffstatter, Ilan Ben Zvi

### Magnets

Neil Marx, Martin Wilson

### Installation and Infrastructure

Sylvain Weisz

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# LHeC CDR:

 Total of ca. 500

- **Details remain to be addressed**

- **Decision to focus R&D work on LR technologies over coming 4 years**

**→ Main Conclusion so far:  
LHeC can be realized in  
parallel with HL-LHC if  
necessary studies are not  
delayed!**